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ABSTRACT

Population reduction through trapping is among the most common techniques used to mitigate damage caused by pocket gophers in a variety of crops. A new trap called the Gophinator was recently developed that combined many positive attributes of previous pocket gopher traps. Because efficacy data for this trap was lacking, we compared capture rates of this trap to the Macabee trap, the most commonly used pocket gopher trap in the western U.S. We also addressed factors that may influence the efficacy of traps such as cover status of the trap set, season, gender, and weight of the captured pocket gopher. We found the Gophinator trap was more efficacious than the Macabee, likely due to its superior ability to capture larger pocket gophers, which could increase the efficacy of pocket gopher control programs throughout North America. Covered trap sets resulted in greater capture rates during late spring–early summer but not during autumn. However, covered trap sets required more time to implement and did not result in a greater number of captures for an 8-h workday trapping period. If efficacy is paramount, trap sets should be covered during late spring–early summer, but when time is a constraining factor, trap sets left uncovered will be most efficient. Covering trap sets in autumn provided no tangible benefits.

1. Introduction

Many wildlife species cause extensive damage to agriculture throughout the world. However, in California and throughout many other states in the western U.S., none may be as damaging as the pocket gopher (*Thomomys* spp.) with estimated profit reductions for California growers ranging from 5.3 to 8.8% annually for a variety of commodities (Baldwin et al., 2011). The damage that pocket gophers cause can be quite varied but includes girdling of young trees and vines, consumption of root systems, chewing on buried irrigation tubing, increased water loss and soil erosion from burrowing activity, and increased hazard to farm equipment and farm laborers (Marsh, 1998; Proulx, 2002). An integrated pest management (IPM) program that incorporates multiple techniques to maximize damage control while minimizing the impact to the environment is the most effective approach to control most wildlife pest species, including pocket gophers (Engeman and Witmer, 2000; Sterner, 2008). Control techniques available to mitigate damage caused by pocket gophers include habitat modification, burrow fumigation, the use of toxicants, and trapping (Engeman and Witmer, 2000; Marsh, 1992). Trapping can be a particularly valuable component of an IPM program because it allows for direct enumeration of individuals removed, does not require the use of toxic chemicals, is allowable for use in organic commodities, is an effective follow-up technique to for other less labor intensive control strategies, and can be economical and efficient when the user is proficient at trapping.

Many pocket gopher traps have been created over the last 148 years (see Marsh, 1997 for comprehensive review). Most are no longer in production, but several are still used extensively in North America. The efficacy and time required to set these traps varies across differing trap types but remains relatively unstudied (but see

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Pipas et al., 2000; Proulx, 1997). The most commonly used trap throughout the western U.S. is likely the Macabee (The Macabee Gopher Trap Co., Los Gatos, California, USA) which has been available since 1900 (Marsh, 1998). In contrast, the Gophinator (Trapline Products, Menlo Park, California, USA) is a recently developed trap, with a patent awarded in 2008. The Gophinator incorporates some of the best attributes of several other traps (Marsh, 2011). However, efficacy and efficiency data are needed to determine the comparative utility of this trap for controlling pocket gophers.

There also has been much contention historically as to the need to cover trap sets to exclude light from pocket gopher tunnel systems (e.g., Dixon, 1922; Gamboa, 1975; Howard, 1952; Storer, 1942). Pocket gophers live in closed burrow systems. When the burrow system is exposed to the external environment, pocket gophers typically investigate and plug the opening with loose soil. By leaving a trap set uncovered, this could increase visitation rates to trap sites thereby increasing capture success. However, pocket gophers can be quite cautious when approaching openings in their burrow system (Zuwang et al., 1987) which may lead to fewer captures if they notice the trap in the tunnel system. Understanding the impact covering pocket gopher burrow systems has on capture efficiency, as well as the associated time costs for covering trap sets, is needed to determine the true benefit of this approach.

Furthermore, the impact that season, weight of captured individual, and gender have on capture success is poorly understood and in need of investigation (Proulx, 1997). For example, temperature influences pocket gopher response to burrow openings (Werner et al., 2005) and capture success (Cox and Hunt, 1992). Therefore, seasonal variations in factors such as temperature could influence the need to cover trap sites. Alternatively, large pocket gophers may be better able to pull out of weaker or more poorly designed traps, thereby rendering them less effective, while male or female pocket gophers may be more or less wary of traps. Therefore, we established the present study to address the uncertainty of some of these factors on trap success for pocket gophers. Our specific objectives were as follows: 1.) determine if capture rate differed between Gophinator and Macabee traps, 2.) determine if capture rate differed between covered and uncovered trap sets, 3.) determine if weight, gender, or season influenced capture success between trap types and cover status, and 4.) determine the time required to implement various trap sets to determine which are the most practical for managing pocket gophers in crop fields.

2. Study sites

We selected 12 sites from throughout California for this study. These sites were located in the southern, central, and northern portions of the state (Fig. 1). Alfalfa was grown at all northern study sites while both southern sites were pastures. Grapes were grown at five of the central sites; the other central site was the Kearney

Fig. 1. The location of field sites for this study. Sites trapped during spring included 1–4, 7–8, and 11; sites trapped during autumn included 5–6, 9–10, and 12.

Agricultural Research and Extension Center, Parlier, where traps were set in 14 different commodities.

3. Methods

3.1. Trapping protocols

We captured pocket gophers during late spring–early summer (12 May–10 July; hereafter, spring) and autumn (15 October–17 November) 2009. Seven sites (4 in Central Valley, 2 in northern California, and 1 in southern California) were trapped in spring while 5 sites (2 in the Central Valley, 2 in northern California, and 1 in southern California) were trapped in autumn (Fig. 1). We used Gophinator and Macabee pincer-style traps for this study (see Marsh, 1997, 2011 for description and dimensions of traps). We placed traps into main tunnels of pocket gopher runways and staked them down with wire flags. Approximately half of the trap-sets of each trap type were covered with a 33 × 33 cm piece of black canvas. The edges of the canvas were covered in loose soil to keep light from entering the tunnel system. The other half of trap-sets was left uncovered. We placed ~one cc of peanut butter just beyond the traps to serve as an attractant. At each site, we randomly rotated through a cycle of setting covered and uncovered Gophinator and Macabee trap-sets so that we ended up with approximately equivalent numbers of each trap-set type for each site. We typically established 20 of each trap-set type (i.e., Gophinator covered, Gophinator uncovered, Macabee covered, and Macabee uncovered) at each site for a total of 80 for all sites, except one site in the Central Valley during summer in which we established 10 of each trap-set type. However, we occasionally had fewer or more of a specific trap-set type depending on local trapping needs and circumstances (see Table 1 for exact numbers per site). Traps were set one day and checked the next. Upon capture, we weighed individuals and placed them in plastic freezer bags for identification of gender in the lab. Capture protocols were approved by the University of California, Davis' Institutional Animal Care and Use Committee (protocol no. 15338).

We also recorded the time spent setting traps at four sites to determine if any trap-set type was quicker to set. The time required to find fresh pocket gopher mounds and set traps often varies depending on the trapper, the density of fresh mounds, and how long it takes to find a tunnel system. To minimize this variability, we recorded time for only one trapper, and time was not recorded until the trapper started excavation of the tunnel system. We stopped timing when the entire trap-set was complete.

3.2. Analysis

We calculated capture rates at each study site for each trap-set type by dividing the number of captures by the number of trap-sets receiving a visit by a pocket gopher (a visit constituted sites that resulted in captures, as well as traps that were sprung or plugged by pocket gophers), and we tested for differences in the proportion of captures for male and female pocket gophers for both spring and autumn seasons using a binomial exact test (Zar, 1999). We analyzed capture rate as a two-factor repeated measures analysis of variance (ANOVA) with site as the blocking effect that received all combinations of trap type and cover status (Zar, 1999). Gender was not used as a factor because we could not know the gender of animals visiting the traps unless they were captured. We analyzed the weights of captured pocket gophers as a three-factor repeated measures ANOVA with site as the blocking effect that received all combinations of trap type, trap cover, and gender. If weight did influence capture success, we graphically represented the impact of weight on capture rates (number of captures for each trap type or cover status for a specific weight class divided by the number of trap sites visited for that respective trap type or cover status) through the use of 45-g categories starting at the lowest observed pocket gopher weight to illustrate how capture rates varied as weight increased. We used simple linear regression to relate the median value of each weight class to the ratio of Macabee vs. Gophinator and covered vs. uncovered capture rates (i.e., the capture rate of Macabee or uncovered trap sets divided by the capture rate of Gophinator or covered trap sets, respectively) to quantify how trap-type or cover-status ratios varied across weight classes (Zar, 1999). We conducted all analyses separately for both spring and autumn due to potential seasonal differences in size and behavior.

We tested for differences in the time required to implement a trap-set using a two-factor repeated measures analysis of variance (ANOVA) with site as the blocking effect that received all combinations of trap type and cover status (Zar, 1999); this allowed us to account for the influence that variable soil types and burrow depths might have on the time required to complete a trap-set.

We were also interested in estimating the number of captures we would likely observe in an 8-h workday for each trap-set type. To calculate this, we first estimated the number of trap sets we

Table 1
The number of pocket gopher trap sets (Set), the number of captures (Cap), the number of visited trap sets (Vis), and the rate of capture (%, Cap/Vis) for 4 trap-set types (Gophinator covered, Gophinator uncovered, Macabee covered, Macabee uncovered) from 12 sites across California during late spring–early summer (spring) and autumn 2009.

Season	Site[a]	Gophinator covered				Gophinator uncovered				Macabee covered				Macabee uncovered			
		Set	Cap	Vis	%	Set	Cap	Vis	%	Set	Cap	Vis	%	Set	Cap	Vis	%
Spring	1	22	16	18	89	20	6	12	50	20	6	11	55	22	7	13	54
	2	20	8	10	80	20	7	10	70	20	10	13	77	20	5	9	56
	3	20	12	16	75	24	13	19	68	20	6	16	38	20	6	15	40
	4	10	7	10	70	10	7	10	70	10	3	8	38	10	3	10	30
	7	24	16	23	70	30	12	27	44	27	12	27	44	29	16	29	55
	8	19	11	17	65	22	15	20	75	20	7	17	41	22	7	21	33
	11	20	13	18	72	20	13	18	72	20	14	20	70	21	11	19	58
	Mean				74				64				52				47
Autumn	5	20	13	15	87	20	10	14	71	20	8	14	57	20	8	12	67
	6	21	9	12	75	22	10	14	71	20	5	10	50	24	7	15	47
	9	21	10	12	83	21	8	11	73	20	4	9	44	22	4	9	44
	10	22	17	19	89	19	16	17	94	21	16	19	84	19	8	17	47
	12	21	11	16	69	23	15	19	79	20	9	15	60	22	12	20	60
	Mean				80				75				58				52

[a] Site locations are provided in Fig. 1.

could operate in this 8-h period by dividing the mean time required to set a particular trap-set type by an 8-h period. However, the time spent searching for pocket gopher mounds was excluded from our trap-set times to eliminate this source of variability. Therefore, we added two minutes to all trap-set time periods to account for this search time. We then determined the proportion of trap sets that resulted in a capture for a specific trap-set type, and multiplied this proportion by the mean number of trap sets operated in an 8-h period for the corresponding trap-set type to estimate the number of captures during that time period. We calculated 95% confidence intervals for these values through bootstrapping (Efron and Tibshirani, 1993). Lastly, we utilized a randomization test (bootstrapping; Efron and Tibshirani, 1993) to determine if the estimated number of captures would differ between the trap-set types. We ran 1000 bootstrap iterations of the mean difference in number of captures between the trap-set types, and determined the proportion of values in the resultant ranked frequency distribution below 0. This proportion indicated the probability of a difference in the number of captures between the trap-set types.

4. Results

We captured pocket gophers at 469 trap-sets out of 980 total trap-sets (Table 1). We observed no difference in the proportion of male ($n = 139$) and female ($n = 130$) pocket gophers captured during spring (exact binomial test, $p = 0.626$), but did observe a difference during autumn (male $n = 82$, female $n = 118$; exact binomial test, $p = 0.013$). During spring, the Gophinator ($\bar{x} = 68\%$, SD = 47) exhibited a greater capture rate per visit than the Macabee ($\bar{x} = 50\%$, SD = 50; $F_{1,6} = 14.9$, $p = 0.008$), while covered sites ($\bar{x} = 63\%$, SD = 48) had greater capture rates than uncovered trap sets ($\bar{x} = 55\%$, SD = 50; $F_{1,6} = 7.5$, $p = 0.034$).

Gophinator traps ($\bar{x} = 80\%$, SD = 40) also captured individuals at a higher rate than Macabee traps ($\bar{x} = 59\%$, SD = 49; $F_{1,4} = 44.3$, $p = 0.003$) during autumn. In contrast to spring, we did not detect a difference in capture rate for covered vs. uncovered ($F_{1,4} = 1.1$, $p = 0.364$) trap sets. We did not observe a trap type by cover interaction for either season ($F_{1,6}$ and $F_{1,4} \leq 0.2$, $p \geq 0.639$).

A possible explanation for the difference in capture rate between the trap-set types was the weight of the individual. During spring, we observed a difference in average weight of captured pocket gophers between the trap-set types, with individuals captured in Gophinator traps ($\bar{x} = 130$ g, SD = 40) heavier than those captured in Macabee traps ($\bar{x} = 118$ g, SD = 33; $F_{1,6} = 4.6$, $p = 0.075$). Pocket gophers captured in covered sites ($\bar{x} = 128$ g, SD = 39) were heavier on average than those captured in uncovered sites ($\bar{x} = 121$ g, SD = 35; $F_{1,6} = 4.8$, $p = 0.070$), while males ($\bar{x} = 135$ g, SD = 42) were substantially heavier than females ($\bar{x} = 114$ g, SD = 28; $F_{1,6} = 30.8$, $p = 0.001$). We observed no interactions between any of these factors during spring ($F_{1,6} \leq 2.1$, $p \geq 0.195$). We noted a strong linear relationship between the weight classes of pocket gophers and the ratio of capture rates for Macabee vs. Gophinator traps ($F_{1,3} = 548.8$, $p < 0.001$, $R^2 = 0.996$; $\beta = -0.006$, SE = 0.0002) and uncovered vs. covered trap sets ($F_{1,3} = 20.6$, $p = 0.020$, $R^2 = 0.873$; $\beta = -0.0058$, SE = 0.0013) indicating that for each 45-g increase in pocket gopher weight, Macabee traps were an additional 25% less effective than Gophinator traps and uncovered trap-sets were an additional 17% less effective than covered trap sets (Fig. 2).

During autumn, we also observed a difference ($F_{1,4} = 25.04$, $p = 0.002$) in pocket gopher weights between males ($\bar{x} = 171$ g, SD = 44) and females ($\bar{x} = 119$ g, SD = 23), which we expected. We did not observe a difference in pocket gopher weight due to trap type ($F_{1,4} = 0.8$, $p = 0.434$) or cover status ($F_{1,4} = 0.0$, $p = 0.991$). We also did not observe interactions between any of these factors ($F_{1,4} \leq 0.7$, $p \geq 0.447$). We again noted a strong linear relationship between weight classes of pocket gophers and the ratio of capture rates for Macabee vs. Gophinator traps ($F_{1,3} = 111.5$, $p = 0.002$, $R^2 = 0.974$; $\beta = -0.0039$, SE = 0.0004) indicating that for each 45-g increase in pocket gopher weight, Macabee traps were an additional 26% less effective than Gophinator traps (Fig. 2). We did not see this same trend for uncovered vs. covered trap sets ($F_{1,3} = 0.02$, $p = 0.902$, $R^2 = 0.006$).

The time required to place trap-sets was affected by cover status ($F_{1,154} = 8.1$, $p = 0.005$) with covered sites ($\bar{x} = 325$ s, SD = 88) requiring more time to set than uncovered sites ($\bar{x} = 290$ s, SD = 76). However, we did not see a difference in the number of captures per 8-h period during spring (covered: $\bar{x} = 34.7$, 95% CI = 30.4–39.1; uncovered: $\bar{x} = 32.1$, 95% CI = 26.0–38.1; $p = 0.232$) due to the greater efficacy of covered trap-sets, nor did we see a difference during autumn (covered: $\bar{x} = 32.7$, 95% CI = 22.6–45.3; uncovered: $\bar{x} = 34.4$, 95% CI = 23.4–42.9; $p = 0.465$).

No difference in time ($F_{1,154} = 0.0$, $p = 0.979$) was required to set Macabee ($\bar{x} = 308$ s, SD = 86) and Gophinator traps ($\bar{x} = 307$ s, SD = 82). As such, we observed a greater number of captures per 8-h period (spring: $p = 0.003$, autumn: $p = 0.043$) for the Gophinator (spring: $\bar{x} = 39.6$, 95% CI = 33.8–45.7; autumn: $\bar{x} = 39.6$, 95% CI = 29.9–49.8) than for the Macabee trap (spring: $\bar{x} = 27.3$, 95% CI = 21.0–33.5; autumn: $\bar{x} = 27.5$, 95% CI = 17.5–37.3) given a higher capture rate for the Gophinator during both sampling periods.

5. Discussion

The Gophinator trap was clearly more effective at capturing pocket gophers than the Macabee, resulting in a substantially higher rate of capture and subsequent number of captures in an 8-h period. The Gophinator trap was designed to be a powerful trap that grips the animal high on the body through the incorporation of various components modeled after other pocket gopher traps (Marsh, 2011). For example, the trigger arm was patterned after the Macabee, the winding mechanism that places tension on the spring is similar to the Death-Klutch (P-W Manufacturing Co., Henryetta, Oklahoma, USA) trap, while the pincer arms are similar to the Lewis (no longer in production) and the Fairbanks pocket gopher traps (no longer in production; Marsh, 2011). Although these separate components were modeled after previous traps, alterations were made to improve their functionality. For example, the trigger arm was offset to prevent direct upward pressure on the sternum of the pocket gopher immediately following the triggering of the trap (Marsh, 2011). The presence of this upward pressure could result in a less secure capture, thereby allowing the pocket gopher to escape. This offset is not present in the Macabee trap and may provide a partial explanation for the lower capture success observed with this trap.

Furthermore, the capture mechanism for the Gophinator consists of a rotating pincer arm that clamps to a stationary arm. This is in contrast to the Macabee which uses an upward thrusting pincer mechanism to clamp down on the pocket gopher. This difference in capture mechanism also likely increased the comparative effectiveness of the Gophinator as the upward thrusting motion of the Macabee trap likely forced the connecting points of the pincers lower on the pocket gopher allowing it a greater chance to escape the trap. The swinging-arm mechanism of the Gophinator regularly captured individuals around the chest cavity resulting in a more secure capture.

The disparity in capture rates for the two traps was particularly evident for larger pocket gophers during spring. This is an especially important point, as larger females are more fecund than smaller individuals (Miller, 1946). Therefore, their removal is

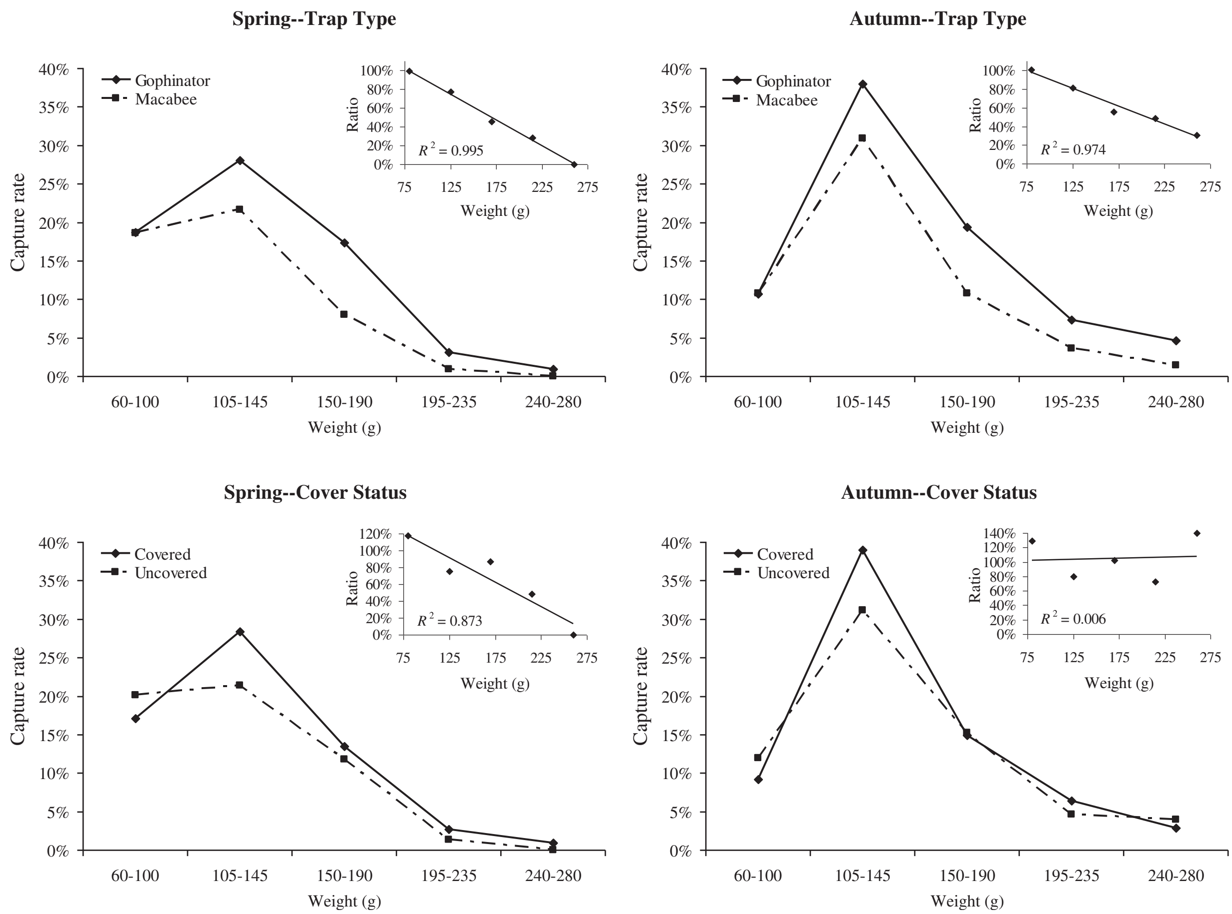

Fig. 2. The percentage of visited trap sets with captures (Capture rate) for 45-g weight categories of pocket gophers for spring and autumn seasons. Comparisons are provided for Gophinator vs. Macabee traps and covered vs. uncovered trap sets. Also included are regressions of weight classes compared to the ratio of Macabee vs. Gophinator capture rates (Ratio) and uncovered vs. covered trap-set capture rates (Ratio).

important to effectively control pocket gophers in crop fields. The difference in capture rate between the two trap types was not as great for smaller pocket gophers as evidenced by the strong linear relationship between the weight of pocket gophers and their associated capture rates for Macabee vs. Gophinator traps (Fig. 2). This suggests that in areas where pocket gophers are relatively small, individuals using the Macabee trap may attain capture rates close to that of the Gophinator.

Interestingly, weight did not substantially influence capture rates during autumn. It is unclear why weight had less influence during this season. It may have been due to a large preponderance of females present during autumn (118 females vs. 82 males), as average female weights were substantially less than males (119 g vs. 171 g) during this season. As with spring, we observed a strong linear relationship between differing weight classes of pocket gophers and associated ratios of capture rates between Macabee and Gophinator traps (Fig. 2). Therefore, because females were more prevalent yet lighter than males during autumn, their preponderance may have masked the impact of weight on capture rates between the two trap types.

Alternatively, the lack of influence of weight during autumn could have been due to the higher overall capture rates we observed during this season. Cooler, but not cold, temperatures increase pocket gopher activity which increases the susceptibility of gophers to traps (Cox and Hunt, 1992; Loeb, 1981). Therefore, increased movement may negate the impact of weight on capture success, as well. Ultimately, more research is needed to identify the factors influencing differential capture rates between Gophinator and Macabee traps during autumn.

Covering trap sets during late spring and early summer resulted in greater capture success of pocket gophers. Previous investigations have indicated increased capture success for covered vs. uncovered trap sets for pocket gophers given their preference for closed burrow systems (Dixon, 1922; Howard, 1952; Storer, 1942). In contrast, Gamboa (1975) noted no effect of cover status on capture success of pocket gophers; we also observed no cover effect during autumn. Pocket gopher plugging behavior is influenced by external temperatures, with plugging more prevalent at extreme temperatures (Werner et al., 2005). Likewise, greater capture success of pocket gophers has been correlated with cooler temperatures presumably due to increased activity (Cox and Hunt, 1992). Therefore, high temperatures during late spring and early summer may have resulted in greater plugging behavior before reaching the uncovered traps, while mild autumn temperatures may have increased activity.

The size of pocket gophers influenced susceptibility to uncovered trap sets during spring as well, as heavier pocket gophers were captured at a lesser rate at uncovered trap sets. Heavier pocket gophers are generally representative of older individuals, especially within populations. Older, more experienced pocket gophers may be more observant of their surroundings, which if true, would make them less likely to be captured in traps (Miller, 1952). Covered trap sets provide the illusion that nothing abnormal exists in their tunnel system. Therefore, they may react less cautiously when wandering through covered tunnel systems. Open tunnel systems expose the pocket gopher to predation which likely increases the caution that experienced individuals use when approaching this opening (Zuwang et al., 1987). If they notice the trap, they may plug the tunnel before reaching the trap, thereby rending it inoperable. We did not observe a difference between weight of captured pocket gophers and cover status in autumn, likely because we did not observe a difference in capture rate between covered and uncovered trap sets during this season.

Although cover status of the trap set did influence capture success during spring, it had only a third of the impact exhibited by trap type during this season, and had no impact on capture success during autumn. In fact, the increase in efficacy associated with covered trap sites during spring was negated by the increased time required to set covered trap sets. It should be pointed out that these trap-set times did not account for the increased time required to uncover a trap set to check the status of the trap the following day. Therefore, the impact that covering a trap set would have on trap-set time is biased low in this study.

The time required to implement pocket gopher control methods is often a limiting factor to many farmers and ranchers, with methods that more quickly control pest species typically preferred (Baldwin et al., 2011). As such, individuals interested in controlling moderate to large pocket gopher populations may prefer to leave trap sets uncovered, given the time savings associated with this approach. However, pocket gophers often become trap shy if they spring a trap but escape, making them more difficult to capture later (Marsh, 2011). Minimizing this possibility would likely be of interest to individuals with only a few pocket gophers to remove, particularly in areas like nurseries and gardens where there is little tolerance for pocket gophers. Therefore, if maximizing capture rates is paramount, covering trap sets in spring could provide slightly better results.

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